



Space & Electronics Group

**Feasibility Study for
Advanced Microelectronics Technology of
Sensor Applications and Ozone Depleters on
Stratospheric Ozone and Deorbiting Space Debris**

CET No. 93-328, Amendment #1, dtd 22-Mar-93

Contract No. F04606-90-D-0001/0049

Point of Contact: Mr. Steve Terwilliger/TIEFC

TRW Sales No. 61197.000

CDRL No. A005-2, ENGINEERING REPORT (FINAL)

31 May 1994

Prepared for:

Department of the Air Force
Sacramento Air Logistics Center
McClellan Air Force Base, CA 95652

Distribution:

SM-ALC/TIEFC 1/0
SM-ALC/TIEFD 1/0
SM-ALC/TICRB 1/0
SMC/CEV 2/0



**Feasibility Study for
Advanced Microelectronics Technology of
Sensor Applications and Ozone Depleters on
Stratospheric Ozone and Deorbiting Space Debris**

Sensor Applications for Stratospheric Ozone

Prepared for:

Environmental Management Division
Space and Missile Systems Center
El Segundo, California

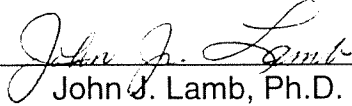
Prepared by:

TRW Space and Electronics Group

in coordination with:

Andrea Sebera
Sebera Advanced Technologies

Approved by:



John J. Lamb, Ph.D.
Program Manager

Introduction and Background

Current space and missile systems technology and launch operations may be causing problems in environmentally sensitive areas. This report focuses on several activities that may have deleterious effects on stratospheric ozone. These include the effects of rocket exhaust, the effects of deorbiting space debris and ground-based sources of ozone depleting chemicals. In addition, an assessment has been made of sensors that can be brought on-line to assist in the quantification of these effects. Finally an assessment of rocket propellants that have a reduced environmental impact has been made.

This program has:

- Gathered relevant information from contractors to generate a relational database for use in mitigation of environmental and worker safety concerns
- Determined the impact of current technology on the stratosphere through the use of sophisticated sensor electronics
- Assessed adverse environmental effects of current technology
- Assessed tropospheric/stratospheric interchange of the constituents of rocket exhaust.

This study assesses the effects of space operations on the environment, with the goal of inserting advanced technology into existing and future systems. This advanced technology will be used to mitigate the adverse effects.

Chlorofluorocarbons and other ozone depleting chemicals, ODCs, are used extensively as refrigerants and precision cleaning agents. Because these substances contribute to stratospheric ozone depletion, their use will be banned in this country after December 31, 1995. Therefore, eliminating releases of these compounds is essential and steps towards this goal must be implemented as soon as possible. Cost effective alternatives to ODCs that minimize the use of hazardous substances must be identified, tested and implemented over the next year to accommodate the phaseout.

In addition to ODCs, hazardous materials and waste are encountered in many aspects of missile systems testing and operations, from motor pool activities to hypergolic fuels waste streams. Mitigation of these hazards is a vital goal related both to worker safety (HazMat data as a guide to the selection of alternative materials and processes) and long-term environmental concerns (HazDisp data).

De-orbiting debris, as it passes through the stratosphere, can affect ozone in several ways, as discussed below. These effects were assessed by performing both laboratory studies and modeling calculations. Objects that reenter the Earth's atmosphere can produce NO_x in the bow shock, which is a known cause of ozone depletion. Although the space

vehicle may survive to impact there may be some associated ablation. It is important to identify the gaseous and solid species that are produced as a result of space debris burn-up. For example, spacecraft and rocket motors are composed of metal alloys and composite materials. When these materials undergo ablation, metal oxides, hydrocarbon fragments, and free radicals are produced. Radicals and hydrocarbon fragments in the form of OH, CN, CH, etc. can react directly or indirectly to consume ozone. A potentially large amount of gaseous NO_x can result from burning debris in the atmosphere when a nitrogen-bound chemical in the debris reacts with ambient oxygen through the "prompt NO mechanism." These sources of ozone depletion need to be assessed for an individual reentry event as well as a scenario of annual events.

The metal oxides may end up as micron size particles which will slow down in the stratosphere and remain there for a considerable time. These oxides and other particulates such as soot that may form from composite materials can provide surfaces for heterogeneous destruction of ozone. Little is known about the role of these materials as catalysts, but it has been established that heterogeneous reactions on natural ice crystals in the Antarctic are a major factor in bringing about the observed ozone hole. There is a clear need for laboratory measurements on surface reactions of ClO_x or NO_x reservoir gases. Investigations performed by Professor Mario Molina at the Massachusetts Institute of Technology have shown some activation of chlorine from atmospheric reservoir species. Details of the experiments and their stratospheric implications are given in this report.

Conventional rocket propellants produce chemical species that may be harmful to the environment in several ways, including destruction of stratospheric ozone. Alternate rocket propellants are being developed that to a large extent mitigate many of these environmental effects. Prior to this report, no complete assessment of these new propellants and methods has been made.

An assessment of alternate rocket propellants has been prepared. Many companies and laboratories are currently working on alternatives to propellants that may produce species harmful to the environment. These species include HCl, Soot, Al_2O_3 , and NO_x . Alternate propellants contain no Cl, O or Al, or contain them in species which are not harmful to the environment. Alternates include the use of fluorine oxidizers, the use of nitrate oxidizers, addition of chlorine scavengers, etc. Different categories of propellants, such as gels, are also being developed. In addition, mechanisms that minimize the amount of fuel required to put a payload in earth orbit are being investigated.

All of the efforts being expended by different individuals. SMC operations require investigation of alternates to conventional propellants as a way of mitigating harmful environmental effects, particularly ozone depletion. An assessment of many of the different options, along with likely environmental impacts of each option will assist SMC in determining the direction for future work

TRW has assessed the importance of chlorine emitted by solid rocket motors (SRMs) in the troposphere. The focus of this report is whether the chlorine from the exhaust of SRMs emitted into the troposphere has the potential to be transported into the stratosphere and thus lead to ozone depletion. This project was performed in conjunction with the Professor Michael Prather at the Department of Geosciences, School of Physical Science, University of California, Irvine.

This report addresses the aspect of the entire program that is stated in the report title.

Sensor Applications for Stratospheric Ozone

Final Report

Background

The US Air Force Space and Missile Systems Center is interested in discerning possible effects of solid rocket motor effluents on stratospheric ozone. One means of assessing these effects is the application of microelectronics devices and satellite sensors. Satellite sensors may collect data over a large area surrounding the location of a solid rocket motor exhaust plume and observe changes in stratospheric ozone, as well as other chemical constituents. This sensor applies not only to solid rocket motors, but to any perturbation of stratospheric ozone. In this report, TRW has developed some data to assess the potential range of instrumentation already either operational or being developed which may shed some light on this question of possible ozone depletion.

TRW asked Andrea Sebera of Sebera Advanced Technologies (SAT), to prepare this matrix of what microelectronics technologies apply in sensor applications of stratospheric ozone. Andrea Sebera has for four years chaired an international AIAA Committee on Standards (Space Based Observation Committee on Standards (SBOS COS) which included an extensive working group on sensors. This group included a major cross section of expertise in the field of satellite sensors. From this work, SAT has developed an extensive network of these sensor experts.

The Matrix identifies specific sensors that detect ozone (O₃) and chlorine monoxide (ClO). This report contains discussion of each sensor in the table and any trade-offs which may apply regarding spatial resolutions vs. detection limits, sensitivities and specificities.

Method

To accomplish this task, SAT has sent Questionnaires (attached) and followed up with phone conversations to approximately 100 satellite sensor science organizations. These organizations and contacts were identified by the American Institute of Aeronautics and Astronautics or developed at one of the NASA Technology 2002, 2003 new technology conferences.

Many of these organizations worked with sensors which were not applicable to detection of ozone or chlorine in the stratosphere. Although data were received from these organizations, it has not been included in the Matrix.

Attached, as background material, is the Contact List used for this study.

NASA and other organizations were contacted to determine whether there were any ground-based instruments or *in-situ* instruments which detected chlorine or ozone in the stratosphere. Some studies from the ground have been made, but none could detect rocket plumes. Therefore, none of this data is included. The following are contacts in this area:

- Dr. Mike Mumma, NASA GSFC, (301) 286-6994

- Dr. Allen Steed, Utah State, (801) 750-2905
- Dr. Dave Mercuray, Univ. of Denver (303) 753-2627

NASA and NOAA do perform some experiments using airplanes with some instruments similar to those on board satellites. However, these do not detect a large area comprehensively over a long enough period to determine what effect, if any, a rocket plume may have. Their studies are aimed at assessing the effect of aircraft. Consequently, none of these are included in the matrix. The principal investigator in super-sonic and sub-sonic studies at NASA GSFC is: Dr. Rich Stolarski, (301) 286-9111.

Sensor Matrix

The Sensor Matrix incorporates the following:

1. **Sensor Name** and technical contact, with telephone number, for information. The contact is often, but not always, the Principal Investigator for the sensor.
2. **Program:** This is either the name of the Program, such as EOS (NASA's Earth Observing System) or the satellite platform that the instrument is flying on or scheduled to fly on, such as UARS, NASA's Upper Atmosphere Research Satellite.
3. **O₃:** This indicates whether O₃ is detected. "Y" means, "Yes it is or can be detected by this sensor." The level of O₃ detected by the sensor is also indicated, if available. Since some sensors sample while others integrate over large samples, these numbers have different meanings. The type of sensor is indicated in the "Data" column gives a clue to the meaning of the resolution indicated in the O₃ column.
4. **CIO:** Similarly, this column indicates whether CIO is detected and the resolution of CIO detected.
5. **Owner:** This indicates the sensor funding organization. For example, a sensor "owned" by JPL is most likely funded by NASA or DoD, but JPL has agreements that permit it to claim ownership. This data is believed to be correct, but sometimes determining the "true owner" was difficult.
6. **Data:** This column contains data which describes the type of sensor. For example, sensors may be radiometers, interferometers, etc. All of these are various forms of spectrometers and use different techniques to discriminate. Where specific bandwidths are known, they are included. Also, information on whether the instrument is operational or is in the development stages is indicated here. Many instruments, such as the MSX suite, are under development. In that case, the most reliable projected launch date is noted.

Sensors

Each sensor will be discussed, relative to the trade-offs of Spatial Resolution vs. Detection Limits.

1. **Earth Cam**: This is an instrument which is part of an ARPA program and will fly on the Galaxy Communications Satellite developed by Hughes. This satellite is scheduled for launch in late 1995, and is a geostationary satellite to fly at 95°W. It scans in a nadir-centered cone of about 5 to 10 km². It could detect ClO, but that feature is not implemented. It has a flexible interface and could possibly fly on a low-earth orbiter. It is cryogenic cooled with a 3-point mount. Since it is geostationary, there is no trade-off between spatial resolution and detector sensitivity.

2. **Microwave Limb Sounder**: Spatial resolution is 4 km vertical by 300 km horizontal. Detector sensitivity is 0.3 ppbv for ClO and 0.3 ppmv for O₃. This is the sensitivity of the version flying on UARS. The EOS version is expected to be 0.1 ppbv and 0.1 ppmv respectively. However, the EOS version is not scheduled for launch until 2002. JPL is very motivated to get this instrument on an earlier launch. They have their engineering model completed already and could be ready for platform integration within one year.

Trade-off: Detector sensitivity goes down inversely with the square root of the number of measurements. For example, 4 measurements gets 2x finer (smaller) sensitivity.

3. **CIRRUS-1A**: This instrument flew in 1991 on the Shuttle. Utah State is motivated to fly it again on the Shuttle or another platform. It does not detect ClO, but it does detect ClONO₂; CFC-11, and CFC-12.

Trade-off: Detector sensitivity is (probably) directly proportional to spatial area, up to some limit. However, the model data to determine this has not been developed.

4. **SPIRIT III**: This instrument is part of an extensive contamination experiment. The intent of MSX is to evaluate the long term effects of rocket launches and other contaminating activities. It is an ambitious undertaking. The entire suite of instruments aboard this satellite 9 UVISI instruments; 6 bands for Spirit III; and the SBV instrument as well as star-trackers, etc. It is scheduled for launch in November 1994.

Trade-off: There is no trade-off as the spatial resolution is set by the size of the sensor. There is however, a trade-off between sensitivity and spectral resolution.

5. **UVISI**: Part of the MSX suite of instruments. This is an ultraviolet image intensifier instrument. It has a 1°x° FOV. It is not especially good for O₃, with an accuracy of only 10-20%.

Trade-off: There is no way to change the geometry. Therefore, there is no tradeoff between spatial resolution and detector sensitivity.

6. **Solar Backscatter Ultraviolet (SBUV/2)**: Solar Backscatter Radiometer which monitors O₃ to a 5% accuracy on a daily global basis. This is a UV nadir-pointing instrument. It has

an O₃ profile of 5% and a total O₃ accuracy of 2%. It has been operational since 1985 in a polar orbit. It has a spatial resolution of 200km².

Trade-off: NOAA has not looked at the trade between spatial resolution and detector sensitivity. However, the instrument scientist does not think there is a trade-off.

7. **High Resolution Dynamics Limb Sounder (HIRDLS):** This instrument is being developed to fly aboard the EOS CHEM I satellite scheduled for launch in 2002. It has 21 channels of instrumentation. Although it cannot see ClO, it can see ClONO₂. It measures O₃ in the stratosphere, troposphere, and mesosphere. Its FOV nominally is 1 km x 10 km at Limb. It profiles O₃ every 4° Lat./Long.

Trade-off: FOV vs. Sensitivity. 25-30 km, can get to 2 to 5% accuracy; at 80 to 100 km, accuracy is 10%. More specific detail has not been modeled.

8. **Stratospheric Aerosol and Gas Experiment (SAGE II & III):** SAGE II is currently flying on the Earth Radiation Budget Satellite (ERBS), while SAGE III is scheduled for a 1998 launch on the EOS AERO SAT satellite. SAGE II measures O₃ to a 5% accuracy in a 2.5 km x 200 km swath which is 1 km vertical. SAGE III will have a 0.5 km x 90 km swath with 1 km resolution. Accuracy will be the same. SAGE II measures OCIO to a 25% accuracy over the Antarctica. It has a 2 km resolution over 15-30 m swaths. SAGE II instruments are sensors with solar occultation. SAGE II will be both solar and lunar occultation.

Trade-off: There is no trade off between spatial resolution and detector sensitivity. SAGE takes instantaneous measurements and can spread in attitude and average.

9. **Tropospheric Emission Spectrometer (TES):** This instrument is scheduled to fly on the AM II EOS platform and be launched in 2003. It measures O₃ in the Troposphere only. It does not measure ClO. It measures O₃ to a precision of 3-20 ppmv. It has two spatial modes: 0.5 x 5 km or 5 x 50 km.

Trade-off: There are no known trade-offs between spatial resolution and detector sensitivity.

10. **Total Ozone Mapping Spectrometer (TOMS):** This is a 6-channel monochromatic spectrometer measuring in wavelengths of 308-360 nanometers:

1. 360 nm
2. 331.2 nm
3. 22.2 nm
4. 317.4 nm
5. 312.5 nm
6. 308.6 nm

It has an FOV of 3° and a ground footprint of 50 km². Its accuracy for O₃ detection is 0.5%. The 3rd TOMS will be launched later this year and the 4th in 1996.

Trade-off: Trade-offs were made during design. Once the instrument was designed, sensitivity and spatial resolution are both fixed. Sensitivity is actually fixed finally during instrument calibration prior to integration with the spacecraft bus.

11. **Millimeter Wave Atmosphere Sounder (MAS):** This is an ATLAS Mission instrument which flies on the Shuttle. It measures in cone 6° about nadir making a ground footprint of about a few hundred kilometers. It measures O₃, but does not measure ClO.

Trade-off: It has fixed geometry and therefore there is no trade-off between spatial resolution and detector sensitivity.

12. **ATMOS:** This is an infra-red sensor scheduled to fly on the ATLAS III payload on the Shuttle later this year. It has flown 3 times before, the first being on the SPACELAB Mission in 1985. It has a 1% precision and 5-8% accuracy in total O₃ measurements. It works by looking at the absorption of solar radiation.

Trade-off: Again, this is a fixed spatial resolution instrument. Therefore, there is no trade-off between spatial resolution and detector sensitivity.

13. **HiRoig:** This instrument is funded by the USAF, Environmental Management Division to detect the O₃ loss due to rocket exhaust. However, at this time it does not have a platform or program for launch. Scheduled completion is June, 1996. This is an Ultraviolet Sensor which measures O₃ using solar UV Backscatter. It also measures the polarization of light to remove scattering caused by aerosols. It has a high spatial resolution (2km x 2km x 5 km(deep)) and can also measure ClO.

Trade-off: The instrument can achieve higher sensitivity with greater spatial resolution. However, there is an optimum point if trying to see a rocket plume which is probably 5 - 10 km across in the stratosphere.

CONCLUSION AND RECOMMENDATION:

In conclusion, this study indicates that there are several sensors which may be used to study the effects of a rocket plume on the stratospheric ozone. However, only one of the current applications of these sensors are designed for this, the HiRoig instrument

Sensor Data

No.	Sensor Name	Program	O3	CIO	Owner	Data
1	Earth Cam Dr. Richard Savage Hughes Information Technology Company 303-344-6000	ARPA/TRP Galaxy Comm Sat 95° W	Y 1-2ppm 5-10 km2	Y (potential)	Hughes Aircraft Company	FOV=3200 X 2400 km silicon detectors, 0.4-1.1 µm infrared, 2.0-12.0 µm detects O3 & HCl; in design launch late '95
2	Microwave Limb Sounder (MLS) Joe W. Waters, JPL (818) 354-3025	UARS, EOS	Y .1ppmv	Y CIO .1ppbv	JPL	Limb Sounder. Higher resolutions are being developed for EOS 1998-99 launch
3	CCIRIS-1A Dan Zhou Utah State University 801-750-3645	AFP-675 (STS-39)	Y 10 ppmv 20kmx25km (2km vert)	N	Phillips Lab	Flies on Shuttle; has own data storage capacity; Multispectral radiometer, 2.5 to 25 µm; Interferometer-spectrometer for high res. spectral measurements
4	SPIRIT III Deputy Principal Investigator DCATT(MSX): Dr. Ray Russell 310-336-5528	Mid-Course Space Experiment(MSX) 11/94 Launch	Y 3-20%	Y 3-20%	BMDO APL, Sys Int Utah State Ins	long wave infrared sensor O3,CFC-11,CFC-12 7 arc-min spatial resol. geometry fixed
5	UVISI Bob O'Neill/617-377-4775	MSX 11/94 Launch	Y 10% 1°x1°FOV	N	BMDO APL Instr.	Radiometer, 5 bands: 6-28 µm Imagers, 4, 0.11-0.90 µm Interferometer: 4 -5 µm spectrometer; 0.11 - 0.90 µm 200nm-900nm Image intensifier
6	Solar Backscatter Ultraviolet (SBUV/2) Radiometer Walter G. Planet NOAA/NESDIS (301) 763-8136	NOAA Satellite Monitoring Program Polar Orbiting	Y 5%, profile 2%, total 200km2 swath	N	NOAA	Solar Backscatter Radiometer 180-400 nm 5% Accuracy; total O3 monitoring amount & vertical profile on daily global basis Op since 1985

Sensor Data

No.	Sensor Name	Program	O3	CIO	Owner	Data
7	High-Resolution Dynamics Limb Sounder (HIRDLS)	EOS CHEM-1	Y 2-5% res. 25-30km2; 10% 80km2	N	NASA	O3, ClONO2, in stratosphere, troposphere, mesosphere: Scanning Infrared Limb Sounder Detector IFOV=1 kmx10km horiz. Launch 2002.
8	Stratospheric Aerosol and Gas Experiment III (SAGE III) PI: M. Patrick McCormick, NASA Langley 804-864-2669	EOS SAGE II: ERBS, 10/84 SAGE III: AERO SAT 1998 Launch	Y 5%, 2.5 x 200km 1 km resol.	Y (OCIO) 25%, 15km km 2 km resol.	NASA	O3 & OCIO in stratosphere, troposphere, mesosphere: Earth limb-scanning grating spectrometer (290-1550 nm) Solar Occultation; (III adds Lunar)
9	Tropospheric Emission Spectrometer (TES) Reinhart Beer, JPL 818-354-4748	EOS AM II platform Launch 2003	Y Troposphere only; 3-20ppmv	No	NASA	Nadir & Limb viewing. 2.3-15.4 µm. Spatial res:0.75 x 7.5mrad 7.5 x 75 mrad (wide-angle) .5x5km; or 5x50km
10	Total Ozone Mapping Spectrometer (TOMS) Instr. Scientist: Tom Riley, GSFC 301-286-6807	TOMS (flies in 4 programs)	Y 0.50% FOV 3°, 50kmx50km	No	NASA	6-channel monochromatic spectrometer; 308-360 nm; FOV =3 degrees; ground footprint is 50 km2
11	Millimeter Wave Atmos. Sounder (MAS); Dr. Tim Miller 205-544-1641	ATLAS I & II (SHUTTLE) (first in 1985 on SpaceLab)	Y 6° cone few 100km	N		Flies on Shuttle
12	ATMOS Mike Gunson, JPL 818-354-2124	ATLAS III late '94 launch (SHUTTLE)	Y 1% 0.1ppmv 200km2	N		Microwave Sensor. 1% precision; 5-8% accuracy; looks at absorp. of solar radiation.2km vertical sampling
13	Hiroig Dave McKenzie, Aerospace Corp: 310-336-7036	Hiroig (no platform) compl. date: 6/96	Y 5%	Y 5%	USAF/CEV	Solar Ultraviolet Backscatter Intr. Spat res: 2kmx2kmx5km Designed to look at rocket plumes

SENSOR QUESTIONNAIRE

Fax Response to: Andrea Sebera Fax: (415) 366-0661

Program Name: _____

Operational since (or date scheduled): _____

Sensor Name: _____

Sensor Owner: _____

Frequency Range: _____

Can sensor detect Ozone-depleting chemicals? _____

Which chemicals can be detected? _____

Particle density detected: _____

What is the FOV? _____

What is the resolution (pp_)? _____

Can the sensor detect ozone concentrations? _____

Resolution (pp_)? _____

What platforms does the sensor interface with? _____

What are interface characteristics? _____

Briefly describe experience in using sensor? _____

Does the sensor easily adapt to on-board recording? _____

Explain _____

Other comments or recommendations (Attach additional sheets, if needed)

Contact Name: _____

Address: _____

Phone&Fax: _____